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the abundant supplies of this fuel are of good augury for the mining industry.

To emerge from this valley the railroad tunnels through a shoulder of the mountains, this being the longest tunnel on the whole line—about 3,000 feet. Leaving the mountains the Skeena River is gained at Hazelton, the head of navigation on that waterway and a Hudson Bay post. The line follows the course of the Skeena to the seaboard. In passing to the coast the railroad crosses a region where experiments in fruit culture have proven very promising and it is possible that the Skeena River country will rival the famous Okanagan and Kootenay valleys in southern British Columbia.

The terminus of the road is at Prince Rupert, a natural landlocked bay having an entrance from the broad Pacific a mile in width, with a harbor 11 miles in length.

My own conclusions from an examination of the country is that the center of industrial, commercial, and agricultural activity will move for the most part from southern British Columbia to the north, where the soil is richer, the climatic and physical conditions more attractive, where the winters are mild, and where there is every inducement to develop diversified farming upon an extensive scale. The mineral wealth is great, and the mining regions have the advantage of being in close proximity to farming lands, thus cheapening food supplies.

THE FORCE OF GRAVITY AND METHODS OF MEASURING IT

BY

C. H. SWICK

Coast and Geodetic Survey, Washington, D.C.

In 1665, while watching an apple fall from a tree in his garden, Sir Isaac Newton had the first conception of his great discovery, the law of universal gravitation. He soon after advanced the theory that the attraction between any two bodies in the universe is directly proportional to their masses and inversely proportional to the square of the distance between them, and he afterward proved this theory by computing the attraction between the earth and the moon.

The variation of the force of gravity at different places on the earth was first discovered by Richer in 1672. He transported a clock pendulum from Paris, France, to Cayenne, South America, and not only found the force of gravity to be different at the two places but also found a progressive increase in its intensity from the equator toward the poles. Using this fact as an experimental basis, Newton demonstrated the earth to be not a true sphere but more nearly an oblate spheroid, it being considerably flattened at the poles. It was not until 1743, however, that formulæ were derived, by Clairault, for computing the true form of the earth from observed values of gravity in different latitudes. The need and importance of gravity observations were then realized for the first time.

Early in the Nineteenth Century experiments were begun separately by France and England to determine the exact form of the earth from gravity observations. The force of gravity was determined at several stations along the meridian in France and at other stations in Great Britain. The attempt to compute the form of the earth from these determinations, however, was a failure, for gravity was found not to vary directly with the latitude, as had been supposed, but to have other variations due to the elevation of the station and to the topography surrounding it. To overcome these difficulties it was then decided to extend the series of stations to the equator on the one side and to the highest accessible latitudes of the northern hemisphere on the other, the stations being so selected as to eliminate as far as possible the effects of elevation and topography. These additional stations were occupied by Sabine in 1822. The results were more satisfactory this time and when computed gave fairly consistent values for the form of the earth.

Many gravity stations have been occupied since that time in nearly all parts of the world, and for several reasons these determinations have been important and necessary. Gravity observations give means for obtaining accurate, absolute standards of length and weight, and many useful inferences can be drawn from them regarding the geologic constitution and the condition of equilibrium of the earth's crust. As more stations are occupied, more accurate values of the form of the earth can be computed, and much can be learned regarding the effect of mountain masses in deflecting the plumb line.

Richer's discovery of the difference in gravity between Paris and Cayenne was made accidentally in transporting a clock from one place to the other. His clock, which kept accurate time at Paris, continually lost two seconds daily at Cayenne. In the experiments which followed Richer's discovery the pendulum was found to be not only the most convenient but also the most accurate method of determining the force of gravity, and it has been used since, almost exclusively, for such determinations.

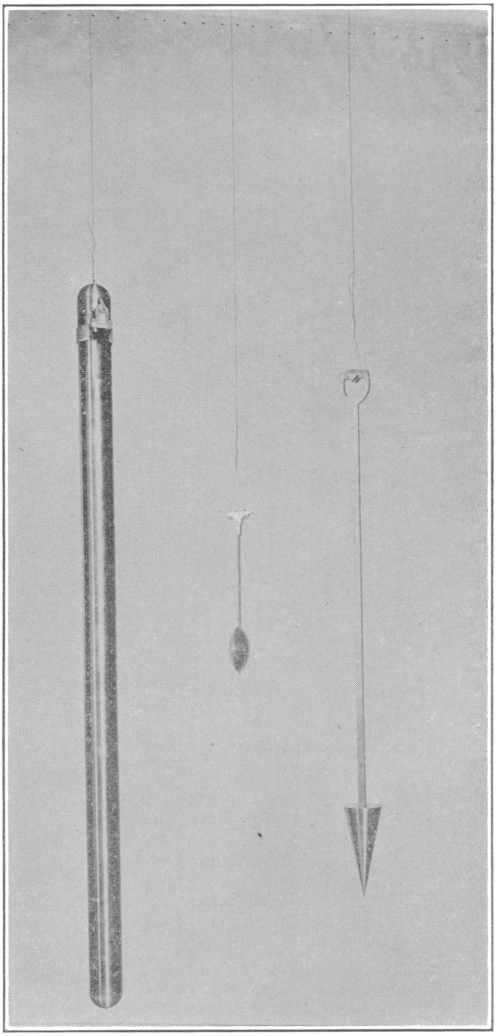

FIG. 1—Two old forms of meter pendulums compared with the quarter-meter pendulum in present use. The one at the left is known as the Pierce Invariable pendulum, the one at the right as the Kater Invariable pendulum, and the one at the center is the quarter-meter pendulum.

At first, the pendulums used were rather crude, and were kept in motion by clockwork. As soon as it was realized, however, that the results must be very accurate to be of value, improved forms of the pendulum were developed whose lengths could be made very stable. These were swung in the open air and were detached, that is, were not connected with machinery of any sort to maintain their motion or register their oscillations. The effective length of these pendulums was made approximately one meter and the period of oscillation was about one second. Some were made adjustable and could be regulated in length to beat seconds at any station. These were reversible, that is, they could be swung with either end up, and their effective lengths at any given station were readily measured, being the distance between the two points of suspension after the pendulums had been adjusted to beat seconds with either end up. Other forms were made rigid and non-adjustable and the force of gravity at any station was obtained by measuring their periods of oscillation at that station and comparing these with their known periods at some base station where gravity had been determined absolutely with the reversible pendulum.

All of these early forms of the pendulum were large, over a meter long, and were difficult to handle and use. Considerable preparation was necessary at each station before they could be swung and the cost per station was very high as compared to the cost with present-day instruments and methods.

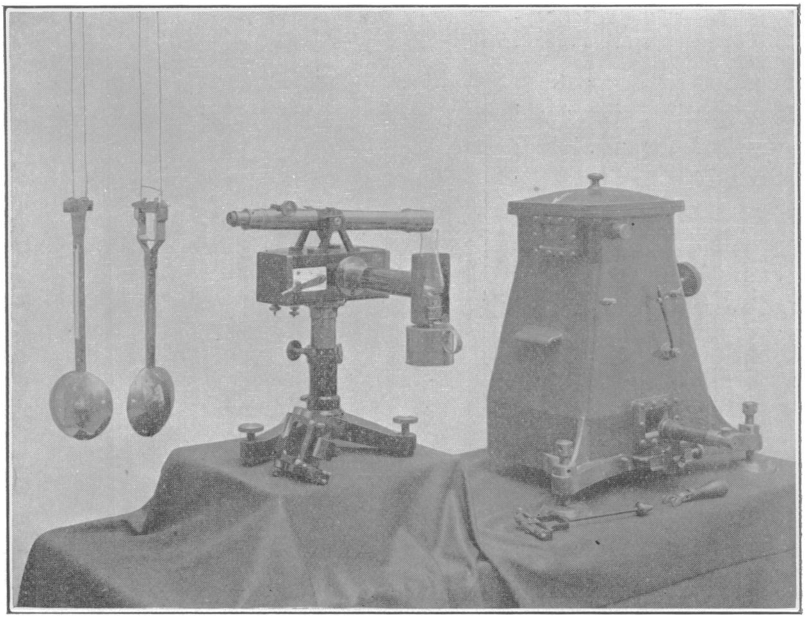

FIG. 2—Gravity apparatus of the Coast and Geodetic Survey in use at the present time. At the left are shown two quarter-meter pendulums, one of which is a stationary "dummy" containing a thermometer. The telescope used for observing the oscillations of the pendulum is shown at the center and at the right is the air-tight brass case in which the pendulums are swung.

The form of pendulum now used by the Coast and Geodetic Survey differs very materially from the early forms and was designed and constructed by members of the Survey about 20 years ago. Like the pendulum designed by Dr. R. von Sterneck in Austria several years previous to this time, it is only one-quarter of a meter long, having been designed for a period of oscillation of about one-half second. The decrease in length of pendulum made a great difference in the size and weight of the accompanying apparatus and decreased very considerably the necessary preparation at a station.

Another step in advance made at this time was in substituting a chronometer for the sidereal clock which had been previously used in obtaining the period of oscillation of the pendulum. In spite of these changes, however, the necessary equipment or apparatus for measuring gravity at a station, when packed for shipment, still weighs more than half a ton, and the packing and transporting of it requires much work and great care.

The gravity outfit in present use in the Survey consists of the following essential parts: Three pendulums, an air-tight brass case in which the pendulums are swung, a telescope for observing the oscillation of the pendulums, two chronometers, an astronomical transit, a chronograph, several thermometers, a manometer, and an interferometer, an instrument for measuring the movement of the case caused by the swinging pendulum.

The method of procedure at a station is as follows: The corrections of the chronometers to the nearest hundredth of a second are first obtained by star observations with the transit; then the pendulums are started and observed every 4 hours for 48 hours, each one of the three pendulums being used for 16 hours. At the end of the swinging, another set of star observations is made by which a second correction of the chronometers is obtained and the rates of the chronometers are then computed. The observed periods of oscillation of the pendulums are corrected for this rate of the chronometers to give their true periods of oscillation.

The pendulum is a simple stem and bob of solid brass, cast in one piece, and differs from an ordinary clock pendulum, in having a small agate plane attached to its head, which rests on an agate knife edge in the case, and in not being connected with any machinery to drive it or count its oscillations. The case in which the pendulums are swung has the air exhausted from it during the experiment to less than one-tenth of atmospheric pressure. The resistance of the rarified air and the friction between the knife edge and plane are so small that a pendulum will swing continuously for more than 8 hours even though its initial arc is only about one-fifth of an inch.

The oscillation of the pendulum is observed and compared with the beat of the chronometers at the beginning, middle and end of each 8-hour swing, and from these comparisons the average period of oscillation of the pendulum is computed.

The resulting value of gravity at a station, to be acceptable, must not have a probable error of more than one part in 200000. An actual error of one part in 200000 corresponds to an error of only one one-millionth of a second in the period of oscillation of the pendulum. Such accuracy is almost inconceivable, but it is attained with very little difficulty if the observer is accurate and careful. Care is taken to keep the pendulum apparatus at as nearly a constant temperature as is possible and any changes of temperature are carefully observed.

One of the corrections which must be applied to the observed time of oscillation of the pendulum is due to the movement of the case resulting from the swinging of the pendulum. The case is a rectangular brass box about 10 inches square at the base and 15 inches high (inside dimensions), weighing 100 lbs. It is either placed on a solid concrete floor or a special brick or concrete pier is built for it. In spite of these precautions, the swinging of the pendulum through its very small arc causes a rocking of the case, and this in turn effects the period of the pendulum. This small movement of the case is measured by the interferometer, a very delicate instrument which depends in principle upon the interference of light waves. With it distances as small as one ten-millionth of an inch can be measured. Vibrations of the ground due to the passing of a team a city block away or a train a mile away are easily detected, and, in fact, they so disturb the instrument that observations are usually possible only at night, when everything is quiet. The shaking of the ground due

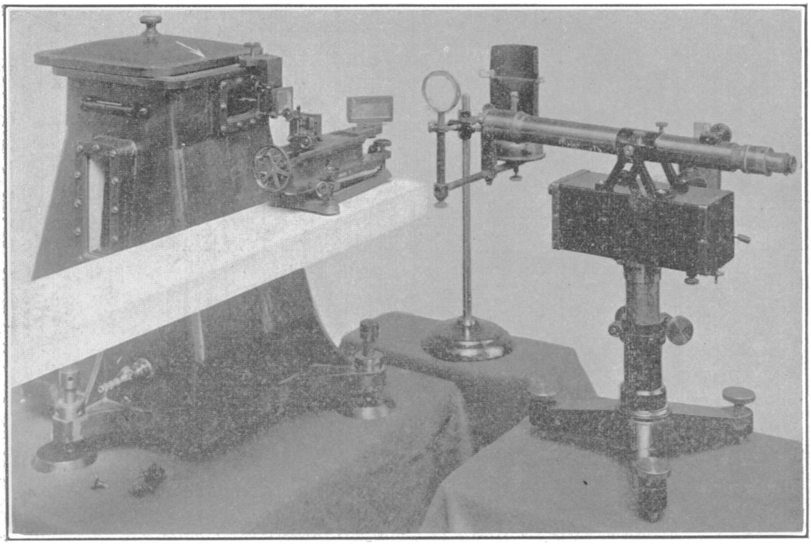

FIG. 3—Interferometer apparatus arranged for observing the movement of the case due to the swinging pendulum. The interferometer is shown resting on the end of the wooden beam at the center of the picture.

to the passing of teams and other disturbing causes, while it has considerable effect on the interferometer, does not have an appreciable effect on the average period of oscillation of the pendulums. The movement of the case due to the oscillation of the pendulum, however, always has a negative effect on the period, that is, it causes the pendulum to beat a trifle slower than if the case were perfectly rigid.

There are 124 stations in the United States at which the force of gravity has been determined. About two-thirds of these have been occupied during the last three years. All determinations are made by the relative method, that is, the force of gravity at a station is obtained by measuring the periods of oscillation of the pendulums and comparing these with the known periods of the pendulums at the base station in Washington, D. C. The value of gravity at Washington was obtained in a similar manner several years ago by using Potsdam, Germany, as the base station where the force of gravity was known from absolute determinations covering many years.

A gravity party consists of two observers. A week or ten days is the usual time spent at a station, but in case of bad weather two weeks or even longer are sometimes necessary for the work. As all the observed values in the field depend upon the periods of the pendulums at the base station, the pendulums are brought back to Washington at least twice a year and tested to see that their periods have not changed or, if they have, to ascertain the amount of the change.

An interesting report on a new method of computing the effect of topography upon the intensity of gravity at a station has been prepared by the Coast and Geodetic Survey, and it will be available for distribution in the very near future.

THE CROCKER LAND EXPEDITION

About July 20 this year Mr. George Borup, Assistant Curator of Geology in the American Museum of Natural History, and Mr. Donald B. MacMillan expect to leave Sidney, Cape Breton, on a special steamer for the Smith Sound region to engage for two years in Arctic researches of great interest. The American Museum of Natural History and the American Geographical Society have approved the plans of these men and will give their support to the enterprise. Yale University and other institutions and individuals